ACEEE Int. J. on Communications, Vol. 4, No. 1, July 2013

Circular Patch Antenna Performance using EBG Structure

A. Bendaoudi and R. Naoum
Laboratory of Telecommunication and Digital Signal Processing, University of Sidi Bel Abbès, 22000, Algeria
aminabendaoudi@yahoo.fr; rafah.naoum@yahoo.fr

***Abstract*—Electromagnetic Band-Gap (EBG) structures are a popular and efficient technique for microwave applications. EBG may be combined with microstrip antenna to increase the diversity gain, the radiation efficiency and/or to suppress surface waves, to reduce the side lobes of the radiation pattern and to increase the bandwidth. In this paper, two different structures will be presented and discussed, which involve: (1) EBG structure fed by circular patch antenna, and (2) circular patch antenna surrounded by one row of EBG structure. The influence of the EBG structure on the radiation patterns is investigated. The effect of the surface waves is also considered. Finally, the reduction of the side lobes of the radiation pattern to increase the bandwidth is presented.**

***Index Terms*— Circular patch antenna, Electromagnetic Band Gap (EBG), Bragg mirror, surface waves, Bandwidth, directivity.**

I. Introduction

The extensive, rapid and explosive growth in wireless communication technology and communication systems is prompting the extensive use of low profile, low cost, less weight and easy to manufacture antennas. All these requirements are efficiently realized by microstrip antennas. The applications of microstrip antennas are wide spread because of their advantages due to their conformal and simple planar structure [1], [2]. In spite of its several advantages, they suffer from drawbacks such as narrow bandwidth, low gain and excitation of surface waves, etc [3]. So to overcome these limitations, the microstrip antenna is combined with the EBG structures in two methods: the first is to use EBG periodic structures that have rejection properties certain microwave frequencies and can improve the reflection and the directivity significantly. The second one is to suppress the propagation of surface wave at the certain operational frequency in microstrip antenna. These methods [4] have eliminated the bandwidth problem for most applications. But limitations of gain and surface wave excitation still remain [3].

In this paper, we propose to analyze two methods; EBG structure is deposed above the circular patch antenna and circular patch antenna integrated in same plan with one row of EBG structure. The remainder of the paper is organized as follows: in section II, a brief description of circular patch antenna. In section III present theories of both structures. In section IV present the simulation results and discussion, the simulation have been done by using High Frequency Structure Simulator (HFSS). The conclusion of this paper is provided in section V.

II. Design Of Circular Patch Antenna

The resonant frequencies of the circular patch can be analyzed conveniently using the cavity model [5], [6], [7]. The cavity is composed of two perfect electric conductors at the top and bottom to represent the patch and the ground plane, and a cylindrical perfect magnetic conductor around the circular periphery of the cavity. Using the synthesis procedure as mentioned in [8], the resonant frequency of a circular patch can be computed as (figure 1):

$$f_0 = \frac{c \cdot Jmn}{2\pi\, a \sqrt{\varepsilon_r}} \tag{1}$$

Where

a = radius of circular patch antenna.

ε_r = dielectric constant.

J_{mn} = *m*th zero of the derivative of the Bessel function or order n.

For dominant mode TM_{11}, J_{mn} = 1.84118 [9] which is extensively used in all kind of microstrip antennas.

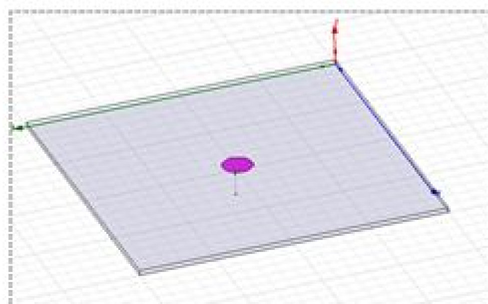

Figure 1. Simulation model of circular patch antenna with dimensions (h=1.57mm, a=4.8mm)

III. Theory of Electromagnetic Band-Gap (EBG) Structure

There are two types of EBG structures to be discussed:

A. Electromagnetic Band-Gap structure fed by circular patch antenna

The 1D-EBG are composed of a stacks periodic dielectric or metallic structures, it have properties of frequency filtering which is illustrated by changes depending on the frequency coefficients of reflection through a material EBG illuminated by a plane wave at normal incidence. Figure 2 shows design of EBG structure without defect.

• *Creation of a Bragg mirror*

A multi-layered structure will be created, that almost completely reflects a perpendicular incoming wave for one

DOI: 01.IJCOM.4.1.1223

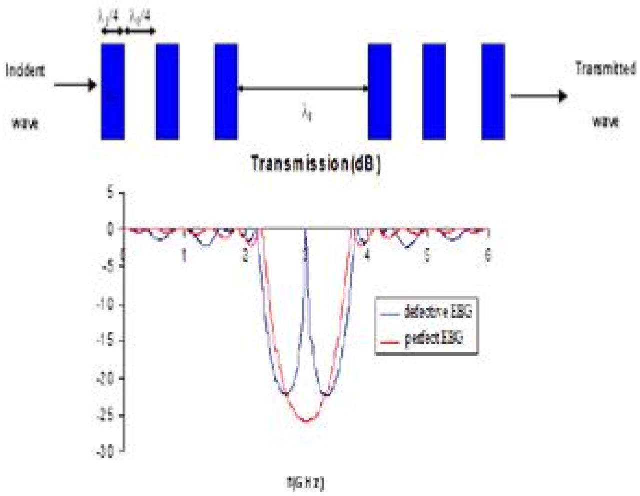

Figure 2. Multi-layered structure with a defect and its transmission for axial incidence

specific frequency (f_0). Therefore, an adjustment to every layer is necessary in order to obtain a destructive interference of the transmitted waves. Every layer has to be λ/4 thick if the multi-layered structure is an alternation between layers of air and layers of a dielectric material [10]. The formulas which represent the thicknesses of the air layer and the layer of dielectric are the following:

$$e_{air} = \frac{c}{4\,f_0} \tag{2}$$

$$e_{diel} = \frac{c}{4\,f_0\sqrt{\varepsilon_r}} \tag{3}$$

Where c is the celerity of light in vacuum.

• *Creation of a resonant cavity*

The introduction of a defect in this structure (figure 3) results in a narrow transmission peak within the band gap. A defect layer of air is introduced, λ_0 thick, the wavelength corresponding with the center frequency f_0 of the band gap. This structure forms a resonant cavity, similar to the Fabry-Perot cavity [10].

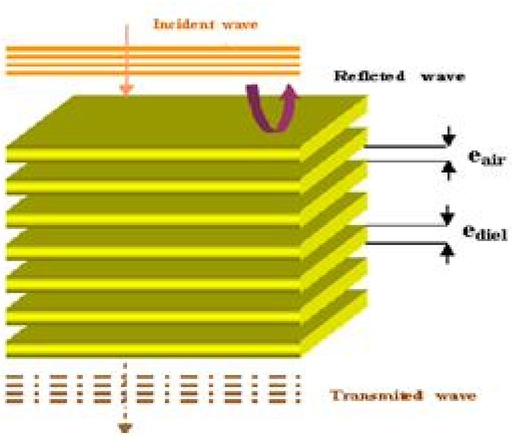

Figure 3. Unidimensionnel Electromagnetic Band Gap structure (1D-EBG)

• *Introduction of an excitation source*

The 1D cavity is formed on one side a perfect plan E (ground plane of the antenna) and the other side of the Bragg mirror. The cavity has a thickness λ / 2 and the Bragg mirror is composed of 3 layers of relative dielectric permittivity ε_r = 2.6 and a thickness λ / 4. The dielectric layers are separated by layers of air, also thick λ / 4 is the wavelength for which the antenna operates. Circular patch antenna fabricated on 100x 100mm Taconic TLY substrate (ε_r= 2.33) and a power source coaxial (Figure 4). The resonant frequency of structure corresponds to 12GHz.

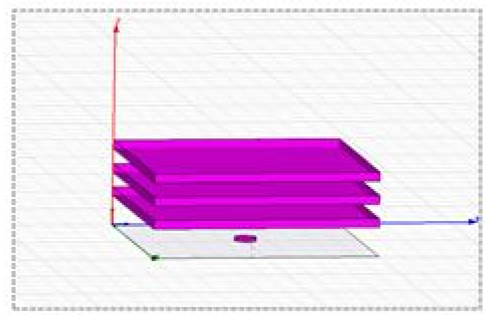

Figure 4. Simulation model of circular patch antenna with 1D-EBG

However, the antenna having finite dimensions, the resonant frequency of the cavity depends on the transverse dimensions of the EBG material. The calculation of the latter can be approximated by the formula [11]:

$$f_0 = \frac{c}{2\pi}\sqrt{\left(\frac{n\pi}{l}\right)^2 + \left(\frac{m\pi}{L}\right)^2 + \left(\frac{p\pi}{h}\right)^2} \tag{4}$$

Where

n,m,p = indices of the cavity mode.

L,l,h =cavity dimensions.

This cavity has the following dimensions: *l*= *L*= 100 mm, *h*= 12.73 mm and should work on the mode 111.

B. Circular patch antenna integrated with Electromagnetic Band-Gap structure

Recently there has been growing interest in utilizing electromagnetic band gap (EBG) structures in the electromagnetic and antenna community. The main advantage of EBG structure is their ability to suppress the surface wave current that reduce the antenna efficiency and radiation pattern [12]. Figure 5 shows design of EBG structure (square shape EBGs are used in a planar structure).

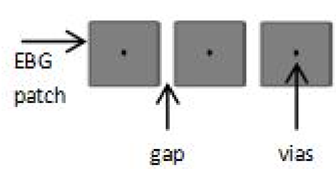

Figure 5. EBG patches

• *Mushroom-like EBG Structures*

Mushroom-like EBG consists of a ground plane, a dielectric substrate, metallic patches and vias that connecting the patches to the ground plane. The structure of this EBG and its equivalent lumped LC elements is shown in Figure 6.

DOI: 01.IJCOM.4.1.1223

The inductance and capacitance of the circuit are due to the shorting vias and the spacing between the adjacent metal patches [13].

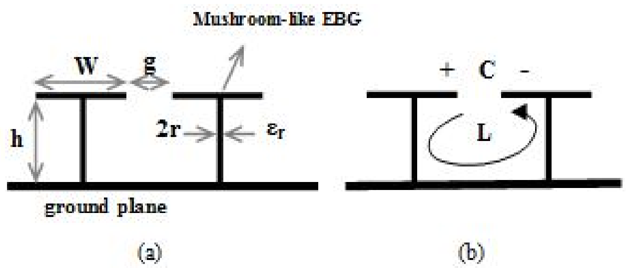

Figure 6. (a) Mushroom-like EBG structure (b) Lumped LC model.

$$f = \frac{1}{2\pi\sqrt{LC}} \quad (5)$$

and:

$$L = \mu_0 \mu_r h \quad (6)$$

$$C = \frac{W\varepsilon_0(\varepsilon_r+1)}{\pi} \cosh^{-1}\left(\frac{W+g}{g}\right) \quad (7)$$

where μ_0 the free space permeability.

- *Patch Antenna Surrounded by a Mushroom-like EBG Structure*

Now the mushroom-like EBG structure will be placed around a circular patch antenna used in Section II located half wavelength (12.5mm) far from antenna radiating edges in E-plane with resonant frequency at 12 GHz (figure 7). The parameters of EBG unit cell are: w (EBG patch width)=3mm, g (gap between adjacent patches) =0.5mm, r (radius of via holes) =0.17mm.

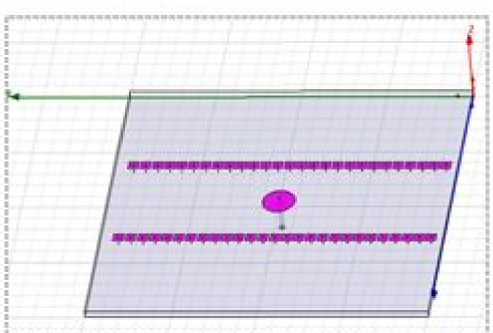

Figure 7. Simulation model of circular patch antenna with one row of EBG

IV. Simulation Results And Discussion

Now-a-days, it is a common practice to evaluate the system performances through computer simulation before the real time implementation. A simulator *"Ansoft HFSS"* based on finite element method (FEM) has been used to calculate return loss, impedance bandwidth, radiation pattern and gains. This simulator also helps to reduce the fabrication cost because only the antenna with the best performance would be fabricated [3].

A. Electromagnetic Band-Gap structure fed by circular patch antenna

- *Reflection coefficient*

The figure 8 shows the graph of reflection coefficient both structures: square patchantenna+1D-EBG and circular patch antenna+1D-EBG.

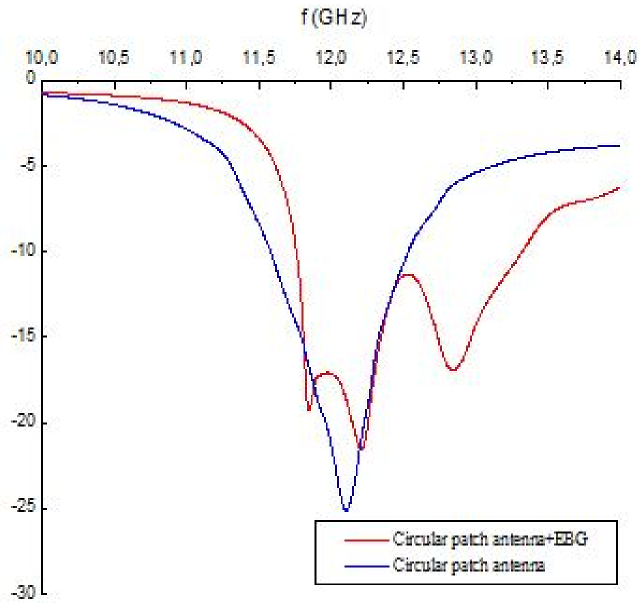

Figure 8. Simulated reflection coefficient (in dB)

From the reflection coefficient curve it is clear that the circular patch antenna+1D-EBG have less reflection -17.73dB and operating frequency at 11.92GHz compared with circular patch antenna has the minimum value is obtained at 12.10GHz and the minimum value obtained is -27dB.

- *2D-Directivity*

The figure 9 below represent the directivity of the two structures in two different planes (Phi = 0 ° and phi = 90 °).

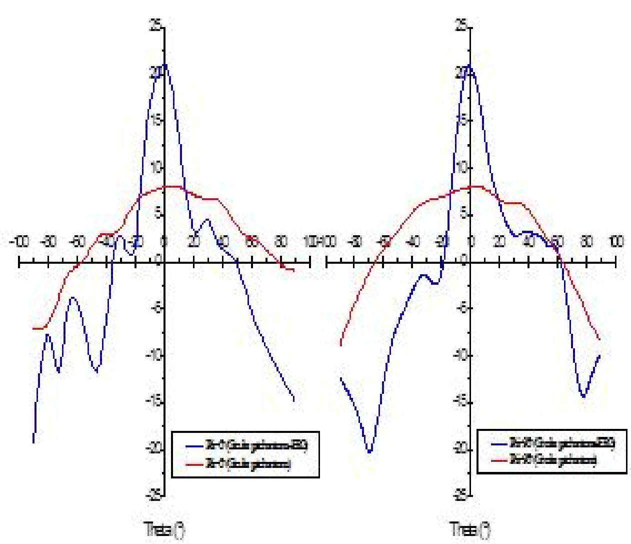

Figure 9. Simulated directivity (in dB)

The maximum directivity gain obtained from the graph is 21.2 dB for circular patch antenna with 1D-EBG structure compared with only circular patch antenna has 7.98dB. Note

DOI: 01.IJCOM.4.1.1223

ACEEE Int. J. on Communications, Vol. 4, No. 1, July 2013

that with the directivity EBG becomes narrower.

• *Radiation pattern*

The figure 10 and figure 11 shows the radiation pattern of the two structures.

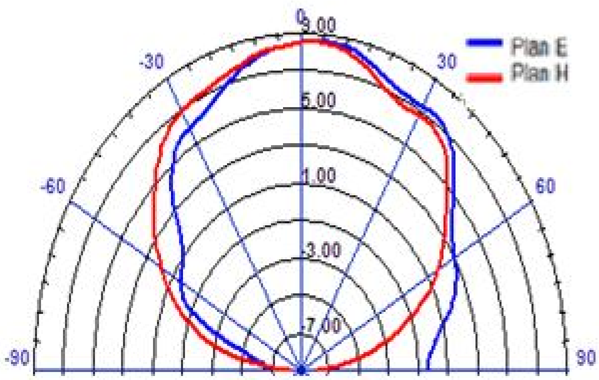

Figure 10. The radiation pattern at 12GHz for circular patch antenna

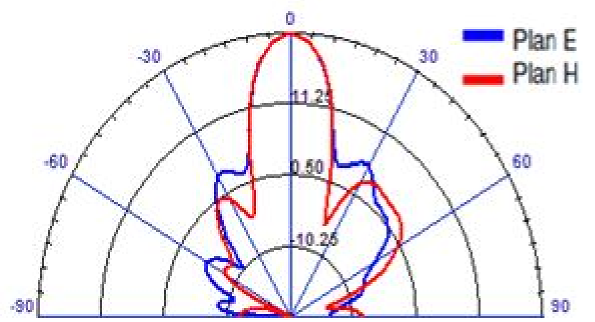

Figure 11. The radiation pattern at 12GHz for circular patch antenna+1D EBG

It is clear from the graph that the radiation is not distributed but directed along a single direction. The Half-Power BeamWidth (HPBW) of circular patch antenna in the E-plane is 54deg and 43deg in the H-plane and the (HPBW) of circular patch antenna+EBG in the E-plane is 58deg and 20deg in the H-plane.

B. Circular patch antenna integrated with one row of Electromagnetic Band-Gap structure

• *Reflection coefficient*

The simulated reflection coefficient that is obtained from circular patch antenna integrated with EBG structures are given in figure 12.

From the figure, it seen that the reflection coefficient for the circular patch antenna is – 27dB at 12.10GHz and for the patch antenna integrated with EBG is -14.3dB at 10.54GHz, so the reflection coefficient of the circular patch antenna integrated with EBG is less compared to the circular patch antenna. Figure 12, at the point of reflection coefficient -10dB, the bandwidth are 350MHz for circular patch antenna and the bandwidth of the circular patch antenna integrated with EBG structure is 500MHz.

• *2D-Directivity*

The figure 13 below represent the directivity of the two structures in two different planes (Phi = 0 ° and phi = 90 °).

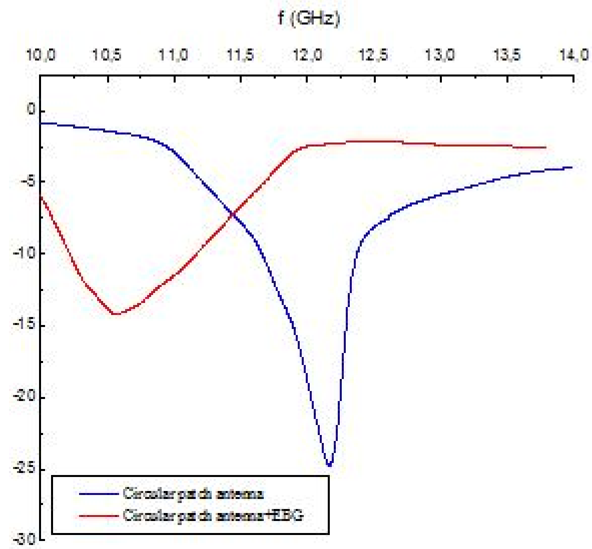

Figure 12. Simulated reflection coefficient (in dB)

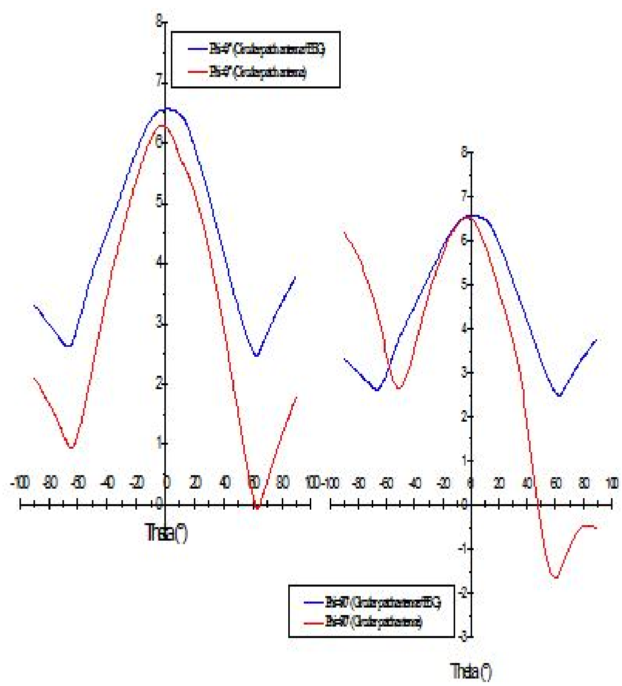

Figure 13. Simulated directivity (in dB)

From the Figure 13, for E-plane the directivity for the circular patch antenna and the circular patch antenna integrated with EBG structures are 7.98dB and 6.59dB.

• *Radiation pattern*

The figure 14 and figure 15 shows the radiation pattern measured only from -90 to 90 deg of the two structures.

From the graph that the circular patch antenna produces a radiation in single direction, and circular patch integrated with one row of mushroom like EBG patches shows large radiation in the both sides. Also, the absence of sides lobes and reduction of surface wave in EBG antenna.

The Half-Power BeamWidth (HPBW) of circular patch antenna in the E-plane is 54deg and 43deg in H-plane. The (HPBW) of circular patch antenna integrated with EBG in the E-plane is 72deg and 75deg in the H-plan.

DOI: 01.IJCOM.4.1.1223

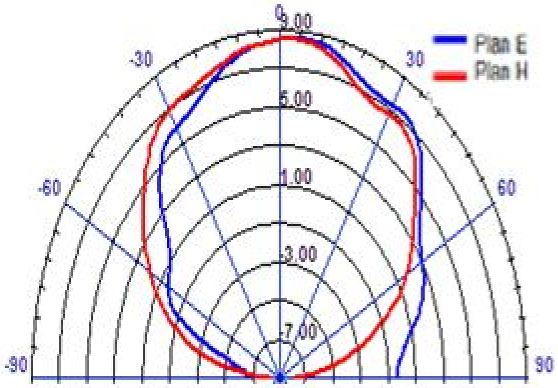

Figure 14. The radiation pattern at 12GHz for circular patch antenna

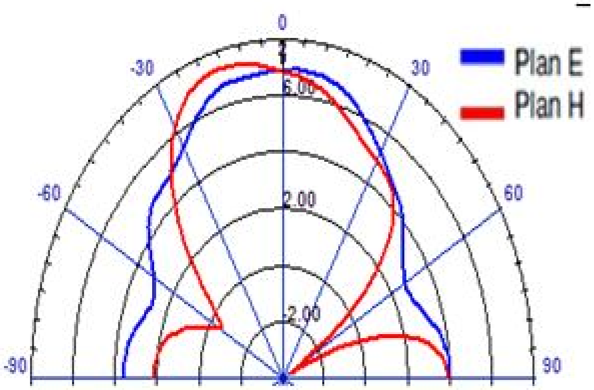

Figure 15. The radiation pattern at 12GHz for circular patch antenna integrated with EBG

Table I shows the obtained simulated results.

TABLE I. THE PERFORMANCE PARAMETERS OF CIRCULAR PATCH ANTENNA ADDED ON EBG STRUCTURE

	Structures studied		
	Circular patch antenna	EBG structure fed by circular patch antenna	Circular patch antenna integrated with EBG
Optimal frequency	12.10GHz	11.92GHz	10.54GHz
Reflection coefficient	-27dB	-17.73dB	-14.3dB
Maximal directivity	7.98dB	21.2dB	6.59dB
Bandwith	350MHz	475MHz	500MHz
E-Plane HPBW	54deg	58deg	72deg
H-Plane HPBW	43deg	20deg	75deg

CONCLUSIONS

This paper has addressed the problem of microstrip patch antennas limitations. We have proposed and investigated two different structures with same physical dimensions that can operate at 12GHz and study the performance parameters of patch antenna when EBG structure added on it which involves (1) EBG structure fed by circular patch antenna, and (2) circular patch antenna integrated with EBG structure. From the simulated results, it is seen that the performances in term of directivity, bandwith and radiation pattern is better of a circular patch antenna that is designed on EBG substrate than the circular patch antenna. So due to its unique properties defined by the structure itself, will find attractive applications in various areas, such as military applications and modern mobile communication.

REFERENCES

[1] Keshtkar, A and Dastkhosh A.R.”Circular Microstrip Patch Array Antenna for C-Band Altimeter System”. International Journal of Antennas and Propagation, 2008.

[2] Anubhuti k, Puran G, Rajesh N, and Teena R.”Optimization Of Dual Band Microstrip Antenna Using Ie3d Simulator for C-Band”. International Journal of Current Research Vol.3 Issue, 11, pp.001-003, October, 2011

[3] Mst. Nargis Aktar, Muhammad Shahin Uddin, Monir Morshed, Md. Ruhul Amin, and Md. Mortuza Ali, Enhanced gain and bandwidth of patch antenna using EBG substrates”. International Journal of Wireless & Mobile Networks (IJWMN) Vol. 3, No. 1, February 2011.

[4] M. Fallah, F. H. Kashani, and S. H. Mohseni, “Side effect Characterization of EBG Structures in Microstrip Patch Antenna”. Progress In Electromagnetics Research Symposium Proceedings, Cambridge, USA, 2010.

[5] Young, M. “The Technical Writers Handbook”. Mill Valley, CA: University Science (1989) 9.

[6] Duncombe, J. U, : Infrared navigation—Part I: An assessment of feasibility (Periodical style). IEEE Trans. Electron Devices, vol. ED-11, pp. 34–39, 1959.

[7] Chen, S, Mulgrew, B. and Grant, P. M.” A clustering technique for digital communications channel equalization using radial basis function networks”. IEEE Trans. Neural Networks, vol. 4, pp. 570–578, 1993.

[8] Lucky, R. W. ’’Automatic equalization for digital communication’’. Bell Syst. Tech. J., vol. 44, no. 4, pp. 547–588, 1965.

[9] Chantalat, R. ’’Optimisation d’un réflecteur spatial a couverture céllulaire par l’utilisation d’une antenne BIE multisources’’. Phd thesis, 2003.

[10] Steyaert, D. ’’Nouvelles structures à bande interdite photonique pour applications antennaires’’. Master work, University Bordeaux1, 2006.

[11] Bingulac, S. P. ’’On the compatibility of adaptive controllers’’ (Published Conference Proceedings style). In Proc. 4th Annu. Allerton Conf. Circuits and Systems Theory, pp. 8–16, New York, 1994.

[12] Mst. Nargis Aktar, Muhammad Shahin Uddin, Monir Morshed, Md. Ruhul Amin, and Md. Mortuza Ali, ’’Parametric performance analysis of patch antenna using EBG substrate’’. International Journal of Wireless & Mobile Networks (IJWMN) Vol. 4, No. 5, 2012.

[13] M.Fallah and L.Shafai, “Enhanced Performance of a Microstrip Patch Antenna using a High Impedance EBG Structure”. Antennas and Propagation Society International Symposium, Vol 3, 2003.

DOI: 01.IJCOM.4.1.1223